Implications for Price Cap Productivity Offset. Conceptually, the productivity offset in the price cap formula is related to the differential in productivity growth achieved by the price cap local exchange carriers and the U.S. economy. The U.S. Bureau of Labor Statistics regularly publishes TFP growth for major sectors of the U.S. economy.[11] The most comprehensive TFP measure published by the Bureau of Labor Statistics is for the private business sector. Currently, the TFP index for the private business sector is available through 1990. The average annual rate of growth for the private business sector between 1984 and 1990 was 0.9 percent. Thus, the TFP growth differential between the LECs and the private business sector since divestiture has been 1.7 percent.

[11]The Bureau of Labor Statistics refers to its TFP measures as "multifactor" productivity. These measures are reported in the Bureau of Labor Statistics publication, Monthly Labor Review. The BLS does not currently publish multifactor productivity for the LECs.

Chapter 2
The Relationship Between Output Growth and Productivity Growth

2.1 Background

Total Factor Productivity (TFP) growth can arise from various sources. One primary source of TFP growth is technological change, shifts in the production function that allow a firm to use fewer inputs to produce the same amount of output. A second primary source of TFP growth is the exploitation of economies of density through output growth. Economies of density are present when average cost falls as more output is provided over a network of fixed size. Therefore, when economies of density are present, increases in output reduce the average level of inputs per unit of output. Consequently, increases in output growth lead to increases in TFP growth and, conversely, decreases in output growth lead to decreases in TFP growth.[12]

Prior to divestiture, the telephone industry experienced rapid rates of output growth, and econometric studies of the industry show that this output growth contributed significantly to TFP growth. Since divestiture, the Local Exchange Carriers (LECs) have experienced more modest rates of output growth, and with increasing competition in their markets, they face the prospect of even slower output growth. Because the provision of LEC services is characterized by economies of density, these reductions in output growth will tend to reduce LEC TFP growth.

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[12]Economies of scale and capacity utilization are other potential sources of TFP growth. Empirical studies have not found either to have a significant impact on TFP growth in the telephone industry.

In addition to the rate of growth in total output, the sources of that output growth can be an important determinant of TFP growth when economies of density are present. In industries with economies of density, prices are typically set above marginal cost for the various services provided by the firm, in order to generate revenue sufficient to cover total cost. When the markup of price relative to marginal cost varies over the services provided, growth in high markup services contributes more to TFP growth than growth in low markup services. Conversely, reductions in the growth of high markup services lead to disproportionate reductions in TFP growth. Much of the increasing competition for Local Exchange Carriers is focused in markets with high price-to-marginal-cost ratios. If competition effectively leads to lower LEC output growth in these high margin markets, LEC TFP growth will also be lower.

This chapter is organized as follows. Section 2.2 discusses in detail the theoretical relationship between economies of density, output growth, and TFP growth. Section 2.3 reviews the literature on economies of density in the telephone industry. We summarize the results of these econometric studies and report their implications for LEC TFP growth. Section 2.4 focuses on particular services provided by the LECs that are subject to emerging competition. These services have high price-to-marginal-cost ratios, and reductions in LEC output growth in these services will likely cause substantial reductions in LEC TFP growth.

2.2 Theoretical Framework

Douglas Caves and Laurits Christensen[13] developed a theoretical framework to analyze the relationship between output growth and TFP growth. Their framework is applicable to firms or industries that provide services over a network, such as the telephone industry. Other industries in which the network structure is important are the railroad, airline, trucking, and electric utility industries. TFP growth in such industries can be related to economies of density, economies of scale, capacity utilization, and technological change. Economies of density describe the change in average cost when more output is provided over a network of fixed size. For LECs, network size can be represented by measures such as the number of access lines. When average cost falls as output rises over this given network, economies of density are present. Economies of scale describe the change in average cost when both output and the size of the network increase. If average cost declines when output and network size increase proportionately, economies of scale are present. Capacity utilization describes the impact on cost when capital is not at its optimum level, i.e. the industry has too much or too little capital.

We use the Caves-Christensen model as a point of departure for exploring the relationship between output growth and LEC TFP growth. The analysis begins with the cost function. The cost function relates the total cost of inputs to the levels of

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[13]"The Importance of Scale, Capacity Utilization, and Density in Explaining Interindustry Differences in Productivity Growth," The Logistics and Transportation Review, March 1988, pp. 3-32.

outputs, the levels of input prices, the size of the network over which the services are being provided, and the level of technology:[14]

$$C = C(Y,W,N,t) \tag{2.1}$$

where
- C = total cost of inputs
- Y = vector of output levels
- W = vector of input prices
- N = size of network
- t = level of technology.

The rate of change in total cost can then be related to the rates of change in outputs, the rates of change in input prices, the rate of change in the network size, and the rate of technological change. Formally, the relationship is:

$$c = \Sigma\, \epsilon_i \cdot y_i + \Sigma\, s_j \cdot w_j + \epsilon_n \cdot n - v \tag{2.2}$$

where
- c = rate of change in total cost
- y_i = rate of change in output i
- w_j = rate of change in input price j
- n = rate of change in network size
- v = rate of technological change
- s_j = share of input j in total cost
- ϵ_i = cost elasticity of output i
- ϵ_n = cost elasticity of network size.

Next, the rate of change in total cost can be decomposed into the rate of change in input prices and the rate of change in input quantities:

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[14]In the Caves and Christensen analysis, capacity utilization of quasi-fixed factors is also incorporated into the analysis. Because Caves and Christensen found that capacity utilization is not a determining factor in telephone TFP growth we have not included it in the model discussed in this report.

$$c = \Sigma\, s_j \cdot w_j + \Sigma\, s_j \cdot x_j \tag{2.3}$$

where

x_j = the rate of change in input quantity j.

Substituting equation (2.3) into equation (2.2) yields the following result:

$$\Sigma\, s_j \cdot x_j = \Sigma\, \epsilon_i \cdot y_i + \epsilon_n \cdot n - v \tag{2.4}$$

The left-hand side of equation (2.4) represents the rate of growth in the quantity of total input. The rate of growth in the quantity of total input is related to the rate of growth in output, growth in network size, and the rate of technological change.

The rate of growth in total factor productivity is the difference between the rate of growth in total output and the rate of growth in total input. The definition of total output used in the TFP measure is based on a revenue weighted average of the rates of growth for the various outputs contained in the index. Thus, it is a "customer oriented" measure of TFP, since the revenue weights used in the output index represent the relative expenditures made by customers for the respective telecommunications services contained in the output index.[15] Moreover, this TFP index differs from estimates of "technological change" (shifts in the production function) that are derived from econometric models. The TFP index constructed in this analysis captures all sources of efficiency improvement--technological change,

[15]Appendix 1 discusses how TFP constructed with a revenue weighted output index allows one to relate output price changes to changes in input prices and changes in TFP.

economies of density, and economies of scale--and, therefore, is more relevant to the discussion of price caps than is an econometric analysis of technological change.

The rate of growth in TFP (the difference between the rate of growth in total output and the rate of growth in total input) can be related to output growth, growth in network size, and technological change via equation (2.4):

$$\begin{aligned} tfp &= \Sigma\, m_i \cdot y_i - \Sigma\, s_j \cdot x_j \\ &= \Sigma\, (m_i - \epsilon_i) \cdot y_i - \epsilon_n \cdot n + v \end{aligned} \tag{2.5}$$

where
tfp = rate of TFP growth
m_i = share of output i in total revenue.

Economies of density are present when the sum of the cost elasticities of output (the ϵ_i) are less than one; economies of scale are present when the sum of the cost elasticities of output and the network elasticity ($\Sigma\, \epsilon_i + \epsilon_n$) are less than one. When economies of scale or economies of density are present, increasing the level of output over the network increases TFP, because the revenue shares are larger than the cost elasticities ($\Sigma\, (m_i - \epsilon_i) > 0$). The contribution to TFP growth of each output depends on its growth rate and on the difference between its revenue share and its cost elasticity. As the difference between the revenue share and the cost elasticity increases, the contribution of output growth to TFP growth increases.[16]

[16]As discussed in Section 2.4, one must recognize that factors which historically led to TFP growth may not provide the same contribution in the future.

2.3 Review of Telecommunications Industry Econometric Studies

Caves and Christensen analyzed TFP growth in six industries: telephone, electric power, airline, railroad, urban bus, and trucking. They examined the contributions of economies of scale, economies of density, and capacity utilization to TFP growth in each industry. Their analysis of the telephone industry relied on the two major econometric studies of the U.S. telephone industry that had been completed at the time of their study.[17] Both these studies show a strong relationship between output growth and TFP growth. Though neither study includes measures of network size, Caves and Christensen concluded that the relationship between output growth and TFP growth was largely due to economies of density.

Two limitations of the studies on which Caves and Christensen rely are that neither study addresses the role of network size on TFP growth and both studies focus on the entire Bell System, which included both the Operating Companies and the Long Lines division. Bell Communications Research provided an econometric cost analysis in 1987 of the Bell Operating Companies that specifically addresses the issue of network size.[18] Using the methods developed by Christensen, Christensen, and

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[17]L.R. Christensen, D.C. Christensen, and P.E. Schoech, "Econometric Estimation of Scale Economies in Telecommunications," in L. Courville, A. de Fontenay, and R. Dobell, eds., Econometric Analysis of Telecommunications, (Amsterdam: North-Holland Press, 1983), and M.I. Nadiri and M.A. Schankerman, "The Structure of Production, Technological Change, and the Rate of Growth of Total Factor Productivity in the U.S. Bell System," in T. Cowing and R. Stevenson, eds., Productivity Measurement in Regulated Industries, (New York: Academic Press, 1981).

[18]"Econometric Estimation of the Marginal Operating Cost of Interstate Access," Special Report SR-FAD-000552, May 1987.

Schoech, Bellcore developed measures of output and input for the Bell Operating Companies, covering the years 1972 to 1982.[19] The econometric models estimated from these data include measures of network size. The estimated models show substantial *economies of density*, but *constant returns to scale*. This means that average cost decreases as output increases over a network of a given size, but average cost does not decrease when output and network size both increase at the same rate. The Bellcore results show that a one percent increase in output, holding network size fixed, leads to approximately a .8 percent increase in TFP.

In two recent papers, Richard Shin and John Ying have attempted to focus on local carriers and incorporate measures of network size. While there are some problems in the data used in both of these papers, their results indicate support for large economies of density. The first of these studies is based on data for 58 local telephone companies over the 1976-1983 period.[20] The output measures used in the study are number of local calls and number of toll calls, which fail to adequately capture the heterogeneity of services provided by local exchange companies. They characterize a third variable used in the analysis, number of access lines, as an output variable, but this variable characterizes the network over which services are being provided. The data also constrain Shin and Ying in the measurement of prices and

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[19]The database contained quarterly observations.

[20]"Unnatural Monopolies in Local Telephone," Rand Journal of Economics, Summer 1992, pp. 171-183.

quantities for the inputs. They assume quantity indexes for capital and for materials, rents, and services can be accurately represented by the number of access lines.

At the sample mean, the cost elasticities of local calls, toll calls, and access lines sum to .94, which shows minor economies of scale. However, the sum of the local call and toll call elasticities equals .25, which shows considerable economies of density. This would imply that a one percent increase in local and toll calls would increase TFP by .75 percent. The second Shin and Ying paper reports a similar analysis of 46 local carriers over the 1976-1987 period.[21] This paper has the same data limitations, and produces results similar to those of the first paper. Together, the two papers suffer from problems due to the data used, but their results are consistent with those of the other studies.

Two additional recent papers have used simpler econometric models in an attempt to directly relate telephone industry TFP growth to industry output growth. Neither study addresses the impact of network size. John Kwoka[22] analyzed the former Bell System companies over the 1948-1987 period. His econometric model relates TFP growth to output growth in addition to other structural variables. His model shows that a one percentage point increase in output leads to a

[21] "Costly Gains to Breaking Up: LECs and the Baby Bells," Review of Economics and Statistics, May 1993, pp. 357-361.

[22] "The Effects of Divestiture, Privatization, and Competition on Productivity in U.S. and U.K. Telecommunications," The Review of Industrial Organization, May 1993, pp. 47-62.

.535 percentage point increase in TFP. Robert Crandall and Jonathan Galst[23] estimate an econometric model that similarly links TFP growth to output growth. They estimate this model for the former Bell System companies, independent local exchange carriers, and the entire telephone industry for the years 1961-1987. They find that a one percentage point increase in output increases TFP growth .34 percent for the former Bell System companies, .55 percent for the independent local exchange carriers, and .37 percent for the entire industry.

Finally, we briefly note a number of recent econometric studies based on the data developed by Christensen, Christensen, and Schoech. These studies have been conducted by David Evans and James Heckman;[24] A. Charnes, W.W. Cooper, and T. Sueyoshi;[25] and Lars-Hendrik Roller.[26] The authors have attempted to estimate models with multiple indexes of output, using the pre-divestiture Bell System data. None of the authors attempt to model network size. The results of these models vary

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[23] "Productivity Growth in the U.S. Telecommunications Sector: The Impact of the AT&T Divestiture," Brookings, February 1991.

[24] "Multiproduct Cost Function Estimates and Natural Monopoly Tests for the Bell System," in D.S. Evans, ed. Breaking Up Bell, North-Holland, New York, 1983; "A Test for Subadditivity of the Cost Function with an Application to the Bell System," American Economies Review, September 1984, pp. 615-623; "Natural Monopoly and the Bell System: Response to Charnes, Cooper, and Sueyoshi," Management Science, January 1988, pp. 27-38.

[25] "A Goal Programming/Constrained Regression Review of the Bell System Breakup," Management Science, January 1988, pp. 1-26.

[26] "Proper Quadratic Cost Functions with an Application to the Bell System," Review of Economics and Statistics, May 1990, pp. 202-210; "Modelling Cost Structure: the Bell System Revisited," Applied Economics, September 1990, pp. 1661-1674.

widely, and these researchers have conflicting interpretations of the data. This is not surprising, since the indexes of output used are highly collinear, and it is not possible to econometrically determine the impact of each index on cost. As noted elsewhere,[27] the collinearity of the variables produces meaningless (negative) estimates of marginal costs for some observations within the samples used for the analysis. This also implies that the estimated cost elasticities are unreliable; hence these models are not of value in determining the relationship between output growth and TFP growth.

In conclusion, recent econometric literature supports the conclusion first reached by Caves and Christensen, namely, that the telephone industry has significant economies of density, and suggests that the magnitude of the impact may even be greater than that estimated by Caves and Christensen. This evidence also shows that economies of density exist for the LECs. Using the more conservative Caves and Christensen results, a one percentage point decrease in output will lead to a reduction in TFP growth of between .3 and .5 percentage points. Over the post-divestiture period, the LECs have been able to achieve TFP growth of 2.6 percent with output growth of 3.5 percent. If future LEC output growth were to be a full percent lower, 2.5 percent, then these econometric studies indicate that TFP growth would be in the 2.1 percent to 2.3 percent range, reducing the TFP growth differential between the LECs and the overall private business sector to the 1.2 percent to 1.4 percent range.

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[27]Leonard Waverman, "U.S. Interexchange Competition," in R.W. Crandall and K. Flamm, eds., Changing the Rules: Technological Change, International Competition, and Regulation in Communications, (Washington, DC, Brookings, 1989), p. 91.

2.4 The Impact of Toll and Switched Access Output Growth on TFP Growth

The econometric studies reviewed in the previous section focus on the overall relationship between output growth and TFP growth, looking at historical trends. They do not address the impact of output growth reductions that occur exclusively in markets where the services have relatively high contributions to joint and common costs (i.e., low marginal costs relative to price).

As discussed in Section 2.2, services that have relatively high contributions to joint and common costs can make substantial contributions to TFP growth. As output grows in these services, total revenue increases more rapidly than total cost. In "real" terms, total output also increases faster than total input. Conversely, a reduction in the rate of growth of output of these services will lead to a reduction in the TFP growth rate.

Two areas with the potential for future reductions in the rate of output growth that also have relatively high contribution margins are intra-LATA toll and switched access. The Local Exchange Carriers are facing increasing competition in both areas, and the LECs are faced with the prospect that future output growth in these areas will be less than historical growth, as competing firms take business away from them.

Equation (2.5) can be used to analyze the impact on TFP growth due to reductions in output growth for these two services. This requires information on cost elasticities of output (ϵ_i) and revenue shares (m_i) for these services. Recently Calvin

Monson and Jeffrey Rohlfs[28] reviewed the evidence on the incremental cost of intra-LATA toll and switched access. They concluded that the long-run incremental cost of these services was no greater than $8.9 billion for the Local Exchange Carriers.[29] To convert the incremental cost to a cost elasticity, one must estimate total economic cost for the LECs. Total economic cost is roughly equal to total revenue; total revenue in 1991 (the year of the Monson-Rohlfs analysis) was $86.5 billion. This implies that the cost elasticity of output of intra-LATA and switched access services is approximately .10. On the other hand, the revenue share of these services in 1991 was .31.

Referring back to equation (2.5), one can see that a one percentage point decrease in the rate of growth for intra-LATA toll and switched access will lead to approximately a .21 percentage point decrease in TFP (i.e., $m_i - \epsilon_i = .21$). Historically, the rate of growth in output for these services has averaged 5.7 percent. It is possible that competition will lower this average rate of growth for the LECs in the future. For example, if the annual average rate of growth were to drop by one percentage point to 4.7 percent, this would reduce the rate of TFP growth from 2.6

[28]"The $20 Billion Impact of Local Competition in Telecommunications," Strategic Policy Research, July 1993.

[29]The Monson-Rohlfs study evaluated three analyses of incremental cost: Bridger Mitchell, Incremental Costs of Telephone Access and Local Use, Santa Monica, The RAND Corporation, 1990; Lewis J. Perl and Jonathan Falk, "The Use of Econometric Analysis in Estimating Marginal Cost," presented at the Bellcore and Bell Canada Industry Forum, San Diego, California, April 1989; and Michael J. Marcus and Thomas C. Spavins, "The Impact of Technical Change on the Structure of the Local Exchange and the Pricing of Exchange Access: An Interim Assessment," unpublished draft.

percent to 2.4 percent, all else equal. This would lower the TFP growth differential between the LECs and the private business sector to 1.5 percent. Similarly, if the output rate of growth for these services were reduced by two percentage points to 3.7 percent, TFP growth would be reduced to 2.2 percent, and the differential would be reduced to 1.3 percent.

Appendix 1

Use of a Revenue Weighted TFP Index for Purposes of Constructing a Price Cap Index

Our LEC TFP study uses a revenue weighted Tornqvist total output quantity index. While marginal cost weighted indexes are appropriate for some other applications, the revenue weighted index is proper when evaluating a price cap index. The reason that a revenue weighted index is proper is that it is "dual" to the customer's price index of telephone rates. The use of the revenue weighted output index allows one to relate increases in output price to changes in input price and changes in TFP. In the following paragraphs we demonstrate this principle mathematically.

First we define total revenue to be R and total cost to be C. Total revenue is related to the prices and quantities of output by the following equation:

$$R = \Sigma P_i \cdot Y_i \tag{A1}$$

where
P_i = the price of output i
Y_i = the quantity of output i.

Similarly, total cost is related to the prices and quantities of the inputs used:

$$C = \Sigma W_j \cdot X_j \tag{A2}$$

where
W_j = the price of input j
X_j = the quantity of input j.

Equation (A1) can be converted into an equation representing rates of change in revenue, output prices, and output quantities:

$$r = \Sigma\, m_i \cdot p_i + \Sigma\, m_i \cdot y_i \tag{A3}$$

where
r = growth in revenues
p_i = growth in output price i
y_i = growth in output quantity i
m_i = the revenue share of output i.

Equation (A2) can similarly be converted into an equation relating the rate of change in total cost to the rate of change in input prices and quantities:

$$c = \Sigma\, s_j \cdot w_j + \Sigma\, s_j \cdot x_j \tag{A4}$$

where
c = change in total cost
w_j = change in input price j
x_j = change in input quantity j
s_j = the cost share of input j.

In market equilibrium, as competitive forces constrain firms to earn only a normal profit, the rate of change in revenue equals the rate of change in cost. Thus combining equations (A3) and (A4), one obtains:

$$\Sigma\, m_i \cdot p_i = \Sigma\, s_j \cdot w_j - \{ \Sigma\, m_i \cdot y_i - \Sigma\, s_j \cdot x_j \} \tag{A5}$$

$$= \Sigma\, s_j \cdot w_j - tfp$$

where
tfp = the rate of growth in TFP.

This means that the rate of change in output prices equals the rate of change in input prices less the rate of change in total factor productivity.

Appendix 2

Output Price Index Calculations

Price indexes for local service, long distance service, and intrastate access service are constructed from rate change information contained in the Form M report. In the Form M, the LECs report the impact of rate changes in terms of changes in revenue. The methodology we use converts the dollar change in revenue to a percentage change in the overall rate level. The percentage changes in rate level are then converted to a price index. In order to apply the methodology to the Form M data, one must determine the following for each reported rate change: (1) the service category (i.e. local, long distance, intrastate access, or other) affected by the rate change; and (2) whether the rate change is a permanent rate change or a temporary surcharge or credit. The following steps describe the construction of the price indexes.

<u>Step 1. Determine the Annualized Value of Permanent Rate Changes and the Effective Value of Permanent Rate Changes in the First Year.</u> The data provided in the Form M are stated in terms of the <u>annualized value</u> of each rate change. Thus when the Form M reports a local rate increase of $20 million, this means that with no change in quantities, the rate change will increase revenue annually by $20 million. However, if a rate change is not initiated at the beginning of the year (January 1), booked revenue for that year will only reflect a portion of the annualized value, since the new rate was not in effect for the full year. Since the price indexes we are

constructing are intended to represent the average price level for the year, the effective value of the rate change in the first year must be calculated. The effective value is equal to the annual value times the fraction of the year that the new rate was in effect.

For example, if the $20 million rate change goes into effect halfway through the year (July 1), the effective value will be $10 million, and this will be the magnitude of the rate impact on booked revenue during the first calendar year. During the second calendar year, booked revenue will reflect the full $20 million rate change. In order to construct a price index that correctly converts booked revenue to quantities, the price index must incorporate the effective value of the rate change in the first calendar year, then incorporate the remaining amount of the annualized value in the second calendar year.

For each service, the annualized and effective values are computed for each rate change, and are summed to a total annualized value and total effective value for each year in the study. We define A_t to be the annualized value of the rate change and E_t the effective value.

Step 2. Calculate Net Credits for Each Year. One time credits and surcharges are different than permanent rate changes in that they have only a temporary impact on the price level. Using the Form M data on one time credits and surcharges, we calculate total credits net of surcharges. We define C_t to be net credits.

Step 3. Tabulate the Reported Revenue for Each Year. In order to convert a service category's effective and annualized values of rate changes into percentage changes in rates, they must be divided by that category's total revenue. Thus booked revenue is collected for local service and billed revenue for long distance and intrastate access. (See Section 1.1 for a discussion of why billed revenue is used for long distance and intrastate access.) We define R_t to be reported revenue.

Step 4. Compute the Percentage Change in the Price Level for Year t. The change in the average price level for year t, relative to the price level in year t-1, is determined by three factors: (1) net credits effective for the year; (2) the effective value of any rate changes that occur during the year; and (3) any carryover from the previous year's rate changes (i.e., the difference between the previous year's annualized value of rate changes and effective value of rate changes). The following formula incorporates these three factors:

$$P_t/P_{t-1} = [(R_t/(R_t - C_t))/(R_{t-1}/(R_{t-1} - C_{t-1}))]$$
$$\cdot R_t \ / \ \{R_t - E_t - [(A_{t-1} - E_{t-1})\cdot(R_t/R_{t-1})]\}$$

where

P_t = price level in year t
R_t = reported revenue in year t
C_t = net credits in year t
E_t = effective value of rate change in year t
A_t = annualized value of rate change in year t.

Once the change in the price level is computed for each year of the study, an index of annual rate levels can be computed by initializing the index at 1.0 in 1984. The index level for each subsequent year is based on the percentage change in the price level for that year over the previous year.